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Problematic Hospital Architecture: Ensuring the Stable Operation of Wireless Communication

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SUMMARY

Wireless communication systems that include LANs and voice communication have been installed in most Japanese hospitals. However, various problems have been discovered. According to a survey by the Japanese Government, many Japanese hospitals have experienced problems that are caused by signal propagation when using wireless communication. If a communication breakdown occurs, current information on patients such as sudden changes in condition or the warning alarms of medical devices may not reach the relevant staff. This can result in a harmful delay in the detection of a sudden change in a patient's condition or in making an erroneous decision. Patient deaths caused by abnormalities in the transmission or reception of signals from the nurse call terminal have been reported. In this paper, we describe problems related to building structure and electromagnetic fields emitted from equipment and make suggestions for correcting them. We also introduce and discuss remedies to the problems that have been proposed in two sets of Japanese guidelines.

Keywords: Wireless Communications; Clinical Environment; Electromagnetic Noise; Building Material

Abbreviations: HIS: Hospital Information Systems; LAN: Local Area Network; PHS: Personal Handy Phone Systems; EMD: Electromagnetic Disturbance; MIC: Ministry of Internal Affairs and Communications; MHLW: Ministry of Health, Labour and Welfare; EMCC: Electromagnetic Compatibility Conference; AIJ: Architectural Institute of Japan; DPS: Dielectric Periodic Structure; FSS: Frequency Selective Surface

Use of Wireless Communication in Hospitals

Most modern hospitals have installed hospital information systems (HIS). An HIS consists of servers, a large number of terminals, and a network. Almost all patient records, including payment information and information about relatives, are stored in HIS servers. Servers and terminals are connected by a local area network (LAN). Staff must quickly and accurately share the most current patient data, especially in hospitals that treat patients in serious condition. To achieve this, enabling reference to and the input of patient data at bedside are required. To this purpose, installing wireless LAN is effective. More than 90% of Japanese hospitals have already installed a wireless LAN [1]. Its application is currently not limited to its use in HIS networks, but also includes communication between medical devices, sensors, and servers. Recently, wireless LAN use by patients has increased in Japanese hospitals because patients have been separated from their families by COVID-19. For voice communication, many hospitals have mobile communication networks (mainly in-house personal handy phone systems, (PHS)) connected to their nurse call systems and wireless medical telemetry systems (WMTS) for patient management. Adding to this, almost all Japanese hospitals now permit the use of cellular phones by staff, patients, and visitors in their buildings, with some limitations.

Wireless communication was historically strictly regulated to prevent electromagnetic disturbance (EMD) with medical devices. But it is now actively used in hospitals for various purposes. Using cellular phone systems has enabled quick and accurate sharing of patient information, thereby increasing labour efficiency and improving patient safety and services. Unfortunately, various problems have been revealed in wireless communication. According to a survey by the Ministry of Internal Affairs and Communications (MIC) and the Ministry of Health, Labour and Welfare (MHLW) [1], around half of all Japanese hospitals have experienced some kind of problem when us-

ing wireless LAN, WMTS, or cellular phones. Many of these problems are thought to be caused by signal propagation, of which several types originate from the building itself or from equipment that has been installed, such as the presence of electromagnetic shields or absorbers between a transmitter and an antenna or from inappropriate antenna installation. Wireless communication has become an integral part of the communication infrastructure of hospitals. However, if it becomes unstable and a communication breakdown occurs, such as that caused by a transfer rate decrease or superimposed noise, important information may not reach a critical staff member (physician, nurse, etc.) This may be the latest information on patients, sudden changes in condition, or malfunction of the warning alarms of devices, such as abnormal operation or stoppage.

This can result in a delay in the detection of a sudden change in the patient's condition or in making an erroneous decision. There have been reports of deaths of inpatients due to delays in the detection of changes in their condition caused by abnormalities in the transmission or reception of signals from a nurse call terminal [2]. Here we point out problems related to buildings and equipment and make suggestions for correcting them that we hope will contribute to the safe and secure use of wireless communication in the future.

Current Issues Related to Wireless Communication in Hospitals

Wireless Communication in Hospitals

The main systems that emit radio signals for communication purposes include the WMTS (Figure 1), nurse call systems connected with an in-house mobile phone system (Figure 2), wireless LANs, and in-house mobile phone systems that are used in many Japanese hospitals. As for in-house mobile phone systems, most Japanese hospitals have installed the Personal Handy-phone System (PHS), for which the maximum power output is 80 mW [3]. Medical devices increasingly have wireless communication functions that transmit and receive instructions and acquire data or that include alarms. In addition, wireless sensors, such as for the detection of bed leaving or the end of an infusion, RFID, and handheld transceivers are also seeing increased use. Each system uses a different frequency band, and overload can occur when these systems operate at peak periods because they can carry enormous amounts of data from various sources, such as voice communication [4,5].

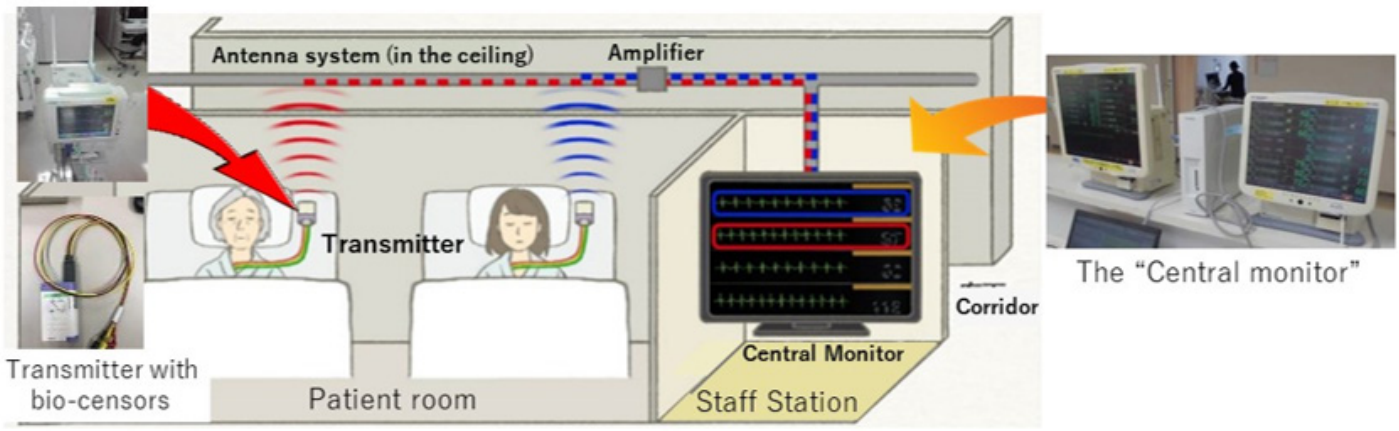

Figure 1: Structure of a Wireless Medical Telemetry System [4].

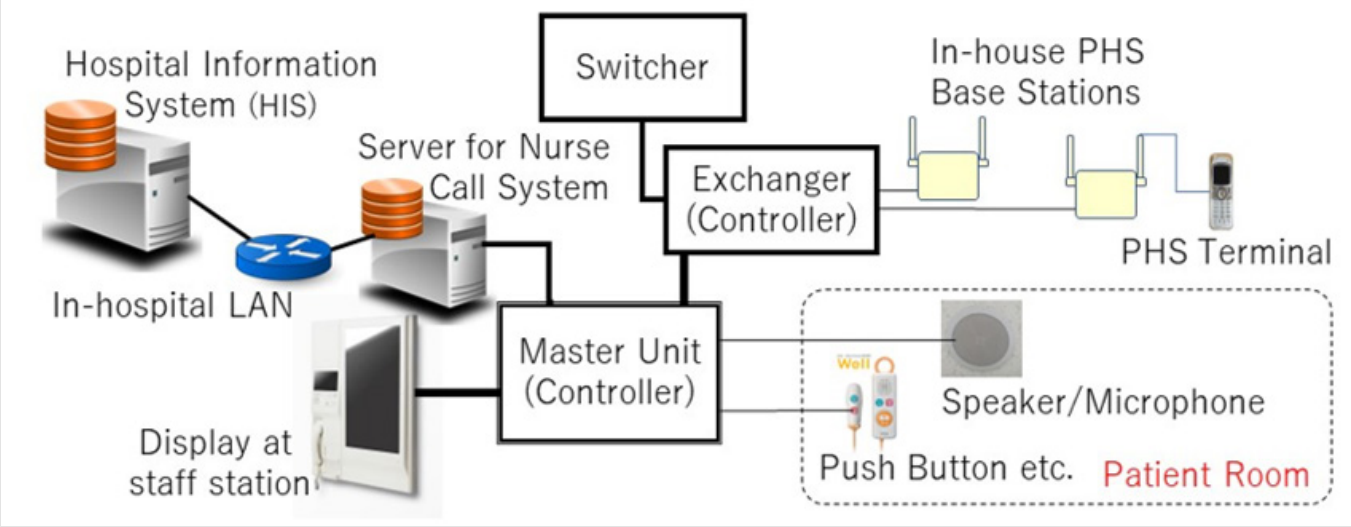

Figure 2: A typical Japanese nurse call system connected with PHS (mobile phone system) [5].

Electromagnetic Disturbance with Medical Devices

The phenomenon of medical devices malfunctioning due to electromagnetic waves emitted by cell phone terminals (Electromagnetic Disturbance, EMD) was first recognized as a problem in the early 1990s [6]. Strong electromagnetic fields can be emitted or leaked during medical treatment, such as by electrocautery and microwave therapy equipment. Microwave therapy equipment radiates a strong electromagnetic field in the 2.4 GHz band and can therefore be a noise source for wireless LANs that use the same frequency band [7]. Early research and regulation focussed on EMD by electromagnetic fields leaked from or induced by communication devices, but later there was much interest on EMD caused by medical devices. This is no longer considered a major issue due to various innovations and regulations, such as reducing the output from cell phone terminals and strengthening the electromagnetic field resistance of medical devices. However, the fact remains that when medical devices are exposed to strong electromagnetic fields, mainly devices with sensors that extract weak biological signals (e.g. electroencephalographs and electromyographs), noise in the measurement results can affect diagnosis and other medical procedures. In recent years, most hospitals have permitted the use of mobile phones in their buildings.

To be effective, the signal from the public mobile phone network must be strong enough to reach throughout the entire hospital building: a weak signal received by a terminal from a base station will lower the quality of a call, as will high radio output from the terminal, which increases the possibility of EMD with medical devices. The need to protect medical devices from EMD, not only in hospitals but also in home care, should be continuously discussed and measures taken.

Electromagnetic Field Radiation Sources in Hospitals

Various devices used in hospitals including non-medical devices, can leak electromagnetic fields. A typical example is interference with WMTS by electromagnetic field leakage from LED lighting fixtures [8]. Microwave ovens, which are often placed in hospital wards, leak electromagnetic fields in the 2.4 GHz band and can be a noise source for wireless LANs [9]. Some of the electricity power supply in hospitals is carried at high current over wires, and this wiring (power lines) may induce magnetic fields in the surrounding area, which can interfere with communication and low-current wiring. Because an electromagnetic field is invisible and the source may be located in a place that is not directly visible, such as in ceilings or walls, it is often difficult to identify the source. In addition, there are various electromagnetic fields that enter from outside the building [10]. Invading electromagnetic fields are considered to be electromagnetic noise to in-hospital communications. There have been reports of WMTS where signals from other hospitals have been displayed on monitors because the channels (frequencies) assigned to patients in their own hospital were the same as those arriving from another hospital [11].

Issues Related to Signal Propagation

As the introduction of wireless communications has progressed, problems other than electromagnetic noise have also become apparent. In particular, 'poor reception' and 'inadequate range of radio reception' have been reported [1]. Equipment that uses radio waves is regulated in each country in which it is to be used, and the output power of its emission is subject to regulation, which may or may not require a license. In Japan, in most cases, licensing is not required for the use of radio waves for communication purposes in hospitals and

the output power is often suppressed. In the case of medical devices, most of which do not use wireless LAN, the upper limit of output power is often suppressed to 1 mW. Because communication is carried out at such a weak output, the quality of communication can deteriorate or be disrupted if there are electromagnetic shields or absorbers between the devices or if there are electromagnetic fields in the same frequency band (electromagnetic noise) around the transmitter or receiver. The former is largely influenced by building materials such as walls, floors, windows, and doors. Hospital buildings have many more walls and doors than office buildings. In addition, communication equipment in hospital buildings is often installed after the building construction is completed. This makes it difficult for wireless communication designers to share information on building materials. In the past, wireless communication was rarely used to monitor or control patients and medical devices, but with the introduction of WMTS and ICT in healthcare, it has become imperative to consider wireless communication from the building planning stage.

Solutions

Realizing Stable Wireless Communication in Hospitals

Various considerations need to be taken into account to ensure stable operation of wireless communication in hospital buildings. The Electromagnetic Compatibility Conference Japan (EMCC) promulgated a guide in 2016 in collaboration with MIC and MHLW, and it was revised in 2021 [2]. The EMCC guidelines mainly target wireless LAN, wireless medical telemetry, and in-hospital use of cellular phones. The Architectural Institute of Japan (AIJ) also published guidelines in 2021 on points to consider when installing WMTS in new hospital buildings, although the scope is limited to WMTS [12]. Here we describe these guidelines and possible solutions to the problems they address.

What Hospitals Should do in Accordance with the EMCC Guide

The EMCC guide recommends that each hospital implement the following to best manage their electromagnetic environment:

(1) Establish a Management System

Establishing a management system includes establishing a place to share information and where discussion of wireless communication and the electromagnetic environment of the hospital can take place. The most important thing is to share information: the main targets of the EMCC guide are the various departments that hospitals use to manage their wireless communication systems. Examples include the information systems department for wireless LANs, the medical device management department for WMTS, the facilities department, and the patient services department for in-hospital use of cellular phones. Based on the many types of devices that emit radio waves for communication purposes, there are many possibilities for forming departments in addition to the above. Careful consideration must be given to devices in the hospital that leak electromagnetic fields and that are sources of electromagnetic noise for wireless communication, as mentioned above. In addition, it is important that signals emitted for communication purposes reach the receiver with the required intensity. The presence or absence of materials between the source and receiver that reflect or absorb signals has a significant impact. Through the sharing of this information between the various management and administrative departments, measures can be effectively taken to prevent interference and disturbance caused by electromagnetic noise. Many large-scale Japanese hospitals have already established a wide range of committees. Issues about wireless communication can be treated in the patient safety committee or committee for medical device management.

(2) Establish Rules of Operation

The formulation and dissemination of rules is also important. In large hospitals, each department may purchase its own specialized communications equipment. For example, frequency bands are assigned for WMTS in Japan, as shown in Table 1. However, delivery monitoring equipment used by obstetrics departments, for example, emits signals in the 429 MHz band. This frequency band overlaps the Band 3 used by Japanese WMTS. Signals emitted from some wireless sensors, such as bed release sensors to prevent wandering, are in the 429 MHz band. In Japan, the 429 MHz band is also assigned to telecontrol systems. This means that there may be invasive 429 MHz electromagnetic signals if building construction is taking place in the vicinity of the hospital. Thus, Japanese standard of WMTS was revised in 2020, and now recommends avoiding using Band 3 [13]. The rules are not only for WMTS frequency bands, but for wireless LAN. There may be cases in which members of the hospital staff have purchased personal tablet terminals or installed wireless LAN access points without authorization. Rules need to be formulated to establish an information sharing system to coordinate the purchase of such equipment. In hospitals with inpatient wards, establishing rules for the use of radio wave transmitting devices (including smartphones) brought in by inpatients / visitors is essential. As mentioned above, each ward may have a microwave oven. Electromagnetic fields that leak from microwave ovens are a known cause of EMD with wireless LAN, as mentioned above [9].

Table 1: Frequency band assigned for Japanese WMTS.

Band name	Frequency (MHz)	Band name	Frequency (MHz)
Band 1	420.0500~421.0375	Band 4	440.5625~441.5500
Band 2	424.4875~425.9750	Band 5	444.5125~445.5000
Band 3	429.2500~429.7375	Band 6	448.6750~449.6625

Rules on reporting procedures when EMD or similar cases occur are also necessary.

(3) User Education

Educational programs are required to familiarize users with the systems and rules described above. The targets include not only staff,

but also patients and visitors. For staff education, ongoing training sessions should be conducted. For patients and visitors, public awareness should include postings in the hospital and explanations at the time of admission.

Points to Note When Introducing Radio Communication Systems, with Reference to the AIJ Guidelines

The target of the AIJ guidelines is limited to WMTS. But the concepts and procedures are applicable to all wireless communication systems. We here focus on the following three concepts.

(1) Sharing Information on Building Structure and Materials

As mentioned above, signals may be reflected or absorbed and thereby not be received if there are electromagnetic absorbers or reflectors between the emission source and the receiving antenna. Poor reception of signals may reduce the transfer rate or be a cause of communication breakdown. When designing for optimum radio propagation, consideration must be given to materials that may not be seen in the floor plan. Points to be considered are shown in Figure 3.

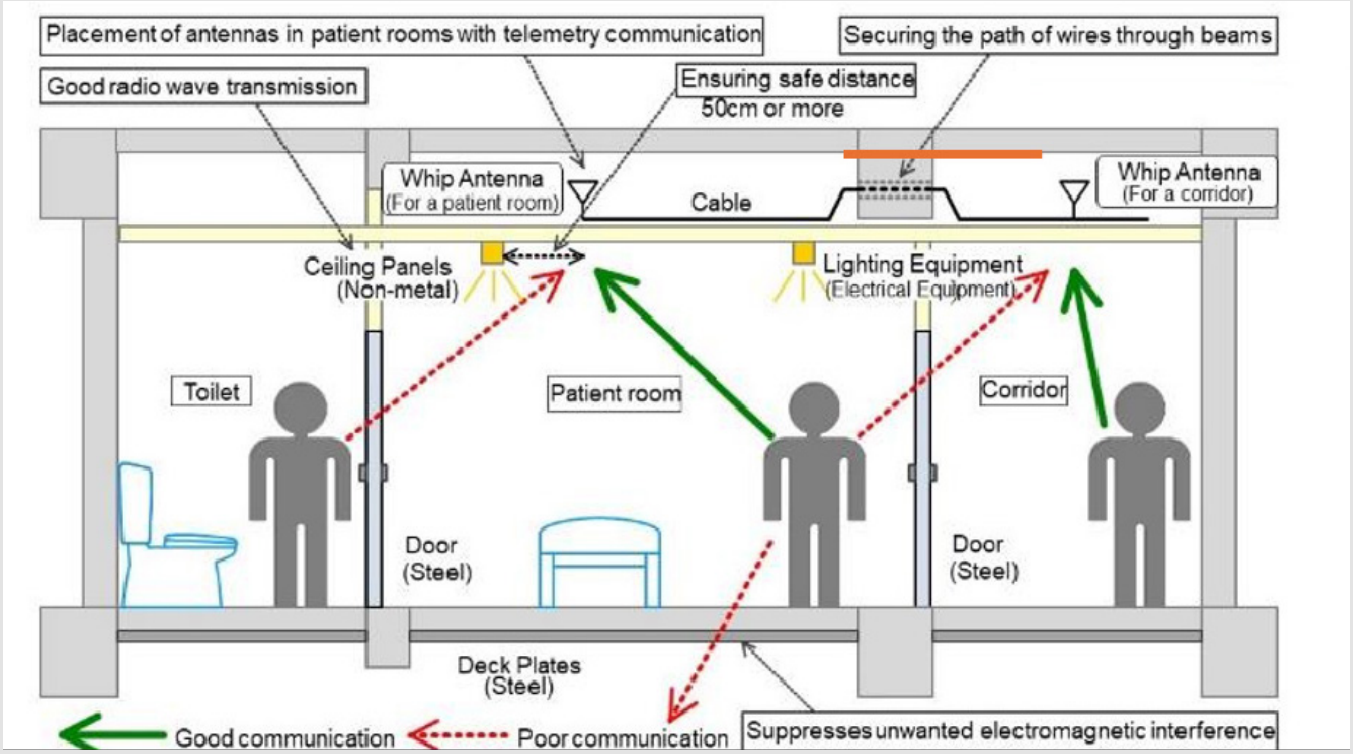

Figure 3: Points to be considered when installing WMTS [13].

(2) Involving all relevant staff from the design stage of hospital construction

Hospital construction is carried out in the following order: building design, frame construction, facilities installation, interior work, and equipment installation. Hospital facilities include air conditioning, water supply and drainage, electricity supply, medical gas supply, and communications. The communication facilities include mainly in-house telephone systems and nurse call systems. Wireless LAN and WMTS are currently treated as equipment. This means that they are installed only after the interior work on the building has been completed. This has caused problems in securing the antenna wiring route and with signal reflection (e.g. reflection by the metal ducts of air-conditioning systems installed in the ceiling). Wireless communication systems are an important part of the hospital infrastructure and should be treated as an integral part of the facility. For these reasons, the departments that manage systems using wireless communication should be involved from the building design stage. The AIJ Guidelines indicate the need at the design stage to clarify where WMTS antennas should be installed. By indicating the range of movement of patients fitted with WMTS transmitters at an early stage, the locations where antennas should be installed can be identified and the routing of cables to these locations can be easily secured. In order to secure a wiring route, it is sometimes necessary to drill holes in structural walls, fire walls, and in some cases beams and to install a pipe system for wiring, which is difficult to do after the interior work has been completed.

(3) Measuring the radio wave propagation conditions

Because electromagnetic waves are invisible, the AIJ guidelines recommend observing radio wave propagation for three purposes. The first measurement is necessary at the design and pre-construction stage to observe the electromagnetic fields already arriving from the surrounding area and to check whether preventative measures need to be taken. Also, the AIJ Guidelines recommend that the signal reception sensitivity from each point where the signals are transmitted be measured after the system is installed and before operation begins. This would confirm that radio signals are propagating as designed. Furthermore, antenna systems deteriorate over time, so periodic measurement of reception sensitivity is recommended. However, this measurement is not required every year. It is sufficient to measure at an interval of several years.

Building Materials and Signal Propagation Control

As mentioned above, signals such as those from cellular phones must reach throughout the hospital building. To avoid crosstalk with WMTS, 400 MHz band signals from outside must not be able to penetrate the building. Other signals should be kept within a limited area, such as the signals of wireless LAN for hospital business, which can include sensitive or private patient information. In order to achieve this, selective shielding of the various frequency bands will be effective. Materials with such a function are being developed [14]. Figure 4 shows an example of a frequency selective surface (FSS). This FSS consists of square ring-shaped conductors attached to a flat glass surface. Figure 5 shows an example of a dielectric periodic structure (DPS). This DPS consists of square air holes made in a dielectric block. The direction of the holes changes every other layer. Construction and communication planners should be responsible for this.

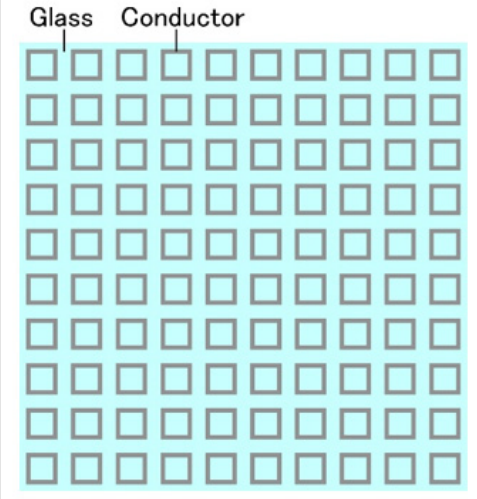

Figure 4: An Example of a frequency selective surface.

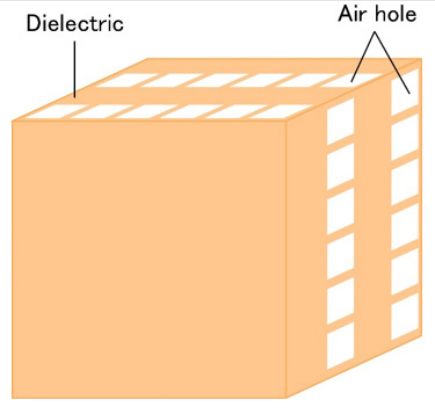

Figure 5: An Example of a dielectric periodic structure.

Prevention of EMD with Medical Devices by Communication Devices

Even though great progress has been made, electromagnetic fields still cause medical devices to malfunction, thus new and updated measures are needed to ensure the safe use of cell phone terminals around medical devices. One such measure is to establish rules for use based on international standards and to insure that not only staff but also patients and visitors comply with them. The international standard for EMC with medical devices is IEC60601-1-2. This standard has been revised several times, and the latest version stipulates that risk management should be carried out by medical device manufacturers and distributors. The standard states that normal operation of medical devices must be ensured at a distance of 30 cm from the device [15]. Another factor is keeping the output from mobile handsets low to protect medical devices from EMD [16]. Although terminal output is limited by law in some countries, LTE and 5G allow terminal output to be controlled by commands from a base station. Controlling terminal output at a low level has been shown to provide a safe environment for medical devices [17], but lowering the terminal output reduces signal reach, so careful consideration must be given to the placement of base stations. The above will go a long way toward preventing EMD.

Conclusion

We have herein described the current situation of wireless communication in Japan, where it has become an integral part of the infrastructure of large hospitals. We also presented measures that each hospital should take according to the guidelines issued by the EMCC and the AIJ. It is our hope that hospitals take greater interest in the stable operation of their wireless communication systems, which will improve the efficiency of healthcare and patient safety. We also hope that construction companies and system suppliers will encourage system staff to become involved at an early stage of building construction. It is important that when hospitals renovate or update their systems, they also take an interest in building materials that cannot be seen on the floor plan. We hope that these actions will enable the stable operation of hospital radio communication.

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